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INVESTIGATION TO IDENTIFY PERFORMANCE CRITERIA AND TEST
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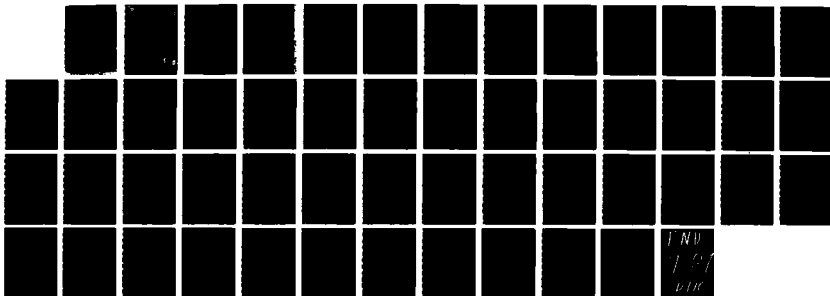
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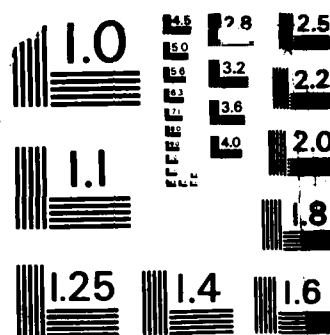
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US Army Corps
of Engineers

Construction Engineering
Research Laboratory

USA-CERL TECHNICAL REPORT M-87/07

March 1987

Improved and New Roofing for Military Construction

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AD-A181 158

Investigation to Identify Performance Criteria and Test Methods for Evaluating Single-Ply Roofing Systems

by
Donald E. Brotherson
Carter Doyle

Two major changes have occurred within the roofing industry over the past 20 years: (1) the performance of traditional built-up roofing (BUR) has declined and (2) a variety of new roofing systems have been introduced into the market. These changes have had great impact on military construction. The most important effect is that premature failure of many BURs installed on military facilities has escalated annual maintenance and repair costs to more than \$100 million. Some of the other systems might be suitable as replacements and for new construction, but the Army lacks performance criteria for specifying these alternatives.

Performance criteria and assessment methods are investigated to identify those which might apply to military construction. It was found that very little research has addressed this field; almost no guidance is available to help specifiers decide which of the new products merit consideration. Most of the techniques used now look at a series of mechanical and physical properties, with very few adopting a systems approach. Only these criteria have been accepted for evaluating the roof as a whole: fire resistance, wind uplift resistance, and impact resistance. These findings prompted a shift in emphasis for this study—toward development of a working framework to study this area systematically. It is recommended that standards be developed to allow accurate prediction of both in-application and in-service performance of single-ply roofs.

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SECURITY CLASSIFICATION OF THIS PAGE

HD H181 158

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704 0188
Exp Date Jun 30 1986

1a REPORT SECURITY CLASSIFICATION Unclassified		1b RESTRICTIVE MARKINGS	
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.	
2b DECLASSIFICATION DOWNGRADING SCHEDULE			
4 PERFORMING ORGANIZATION REPORT NUMBER(S) USA-CERL TR M-87/07		5 MONITORING ORGANIZATION REPORT NUMBER(S)	
6a NAME OF PERFORMING ORGANIZATION U.S. Army Construction Engr Research Laboratory	6b OFFICE SYMBOL (if applicable) USA-CERL	7a NAME OF MONITORING ORGANIZATION	
6c ADDRESS (City, State, and ZIP Code) P.O. Box 4005 Champaign, IL 61820-1305		7b ADDRESS (City, State, and ZIP Code)	
8a NAME OF FUNDING SPONSORING ORGANIZATION HQUSACE	8b OFFICE SYMBOL (if applicable) DAEN-ZCF-B	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c ADDRESS (City, State, and ZIP Code) 20 Massachusetts Ave., N.W. Washington, D.C. 20314-1000		10 SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO 4A162731	PROJECT NO AT41
		TASK NO A	WORK UNIT ACCESSION NO 044
11 TITLE (Include Security Classification) Investigation to Identify Performance Criteria and Test Methods for Evaluating Single-Ply Roofing Systems (Unclassified)			
12 PERSONAL AUTHOR(S) Brotherson, Donald E. and Doyle, Carter			
13a TYPE OF REPORT Final	13b TIME COVERED FROM _____ TO _____	14 DATE OF REPORT (Year Month Day) 1987, March	15 PAGE COUNT 48
16 SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service Springfield, VA 22161			
17 COSAT CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	roofs test methods	
13	13	single-ply roofing systems	
		performance (engineering)	
19 ABSTRACT (Continue on reverse if necessary and identify by block number)			
<p>The U.S. Army lacks performance criteria for specifying alternatives to conventional built-up roofs (BUR) that might be suitable for replacements, new construction, or both. These alternative roofs, which have had a great impact on military and civilian construction, are the result of two major events in the roofing industry over the past 10 years: (1) the performance of traditional BUR has declined and (2) a variety of new systems has been introduced into the market.</p> <p>Performance criteria and assessment methods are investigated to identify those which might apply to military construction. It was found that very little research has addressed this field; almost no guidance is available to help specifiers decide which of the new products merit consideration. Most of the techniques used now look at a series of mechanical and physical properties, with very few adopting a systems approach. Only</p>			
20 DISTRIBUTION AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED LIMITED <input checked="" type="checkbox"/> SAME AS RPT <input type="checkbox"/> OTHER USERS		21 ABSTRACT SECURITY CLASSIFICATION Unclassified	
22 NAME OF RESPONSIBLE NO/DOA D. P. Mann		23 TELEPHONE (Include Area Code) (217) 373-7223	
		24 DESIG. SYMB. Chief-INT	

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→ three criteria have been accepted for evaluating the roof as a whole: fire resistance, wind uplift resistance, and impact resistance. These findings prompted a shift in emphasis for this study--toward development of a working framework to study this area systematically. It is recommended that standards be developed to allow accurate prediction of both in-application and in-service performance of single-ply roofs. (Continued)

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FOREWORD

This investigation was performed for the Office of the Assistant Chief of Engineers, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162731AT41, "Military Facilities Engineering Technology"; Task A, "Facilities Planning and Design"; Work Unit 044, "Improved and New Roofing for Military Construction." The HQUSACE Technical Monitor was Chester Kirk, DAEN-ZCF-B.

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INVESTIGATION TO IDENTIFY PERFORMANCE CRITERIA AND TEST METHODS FOR EVALUATING SINGLE-PLY ROOFING SYSTEMS

1 INTRODUCTION

Background

The roofing industry has seen two major changes during the past 10 years: (1) the performance of traditional built-up roofing (BUR) has declined dramatically and (2) many new roofing systems have been developed and placed on the market. The decline in BUR performance is costing the Department of Defense (DOD) more than \$100 million each year* for maintenance and repair at facilities that have this type of roof. Some of the newer systems show promise as replacements and for new construction, but long-term data on their effectiveness and durability are not yet available. In addition, so many different products are being marketed that it is difficult for a specifier to compare their properties and predict which roof would be the best choice for a given structure.

The Army's current situation is this: BUR is no longer the best choice of roof for all applications--but it is unclear which newer product(s) offers a reasonable alternative.

In the past, most BUR specifications were prescriptive, that is, they called for a particular product and application method for a given type of construction. This kind of specification limits the choice to one roofing system when several products could potentially meet the requirements. In contrast, performance specifications list the functions a roof should provide and the criteria it should meet by describing minimum and maximum physical characteristics. To ensure that all roofing systems receive appropriate consideration in specifying roofs for military construction, the Army needs reliable performance criteria and assessment methods. The goal is to specify roofs that provide the longest maintenance-free service life at the lowest possible cost.

Objective

The objective of this work is to investigate existing performance criteria and testing methods for evaluating single-ply roofing systems. Findings will be assessed for applicability to military construction.

Approach

An attempt was made to collect data by surveying the literature and interviewing knowledgeable representatives from the roofing industry. However, because so little information is available on this subject, the approach was shifted toward developing a working outline that can be used to guide future research.

*Extracted from *Commerce Business Daily* for CY83.

Scope

The exhaustive research and development required to overcome the lack of useful guidance was beyond the scope of this study. Instead, the findings have been compiled into an outline that will help other researchers identify specific gaps in the field of performance criteria and test methods for roofing systems.

Mode of Technology Transfer

Information in this report could serve as background for any future Army studies into this topic. It also could be used to help facilities engineers select replacement and new roofing systems until more comprehensive guidance becomes available.

2 ROOFING TYPES AND PHYSICAL PROPERTIES

Overview

All roofing systems must provide the following basic functions:

- Fire safety
- Heat flow control
- Strength and rigidity
- Economical construction
- Pleasing appearance
- Prevention of air penetration
- Thermal radiation control
- Energy conservation
- Control of water vapor flow
- Durability
- Protection against weather.

It is estimated that conventional bituminous BUR is still used on most low-sloped commercial and industrial roofs in the United States. BUR systems can provide 15 to 20 years of service if they are designed, specified, applied, and maintained properly. Historically, BUR has also been the lowest cost system for these applications.

Experience with alternatives to bituminous BUR has been limited. The newer products, often called "single-ply roofing systems," were first developed and used in Europe; they have been used in the United States for only about 20 years. These systems were developed to overcome problems with conventional BUR, simplify application procedures, and provide improved roofing. Early experience in the United States showed these systems to be far more expensive than conventional BUR. Consequently, for several years, single-ply roofs were used only in special applications for which BUR could not be installed (e.g., domes, folded plates, and curved roofs).

Although single-ply roofing materials are still expensive, these roofs now are competitive in cost with BUR, on both an installation and life-cycle basis. In addition to the cost factor, recent improvements in quality have made single-ply roofing an attractive alternative; modern technology has made significant progress in terms of these systems' performance.

To facilitate an understanding of the performance requirements, it is important to identify the physical properties of these two basic types of roofs. Both BUR and single-ply roofing are used on a wide scale in the United States; however, as stated earlier, the experience with single-ply roofs has been on a much shorter term than that with BUR.

Built-up Roofing

Most low-slope roof construction in the United States consists of bituminous BUR systems. The term "BUR" is used to describe roofs which are composed of two or three elements: a bituminous material and reinforcing felts, with optional surfacing material. The bituminous component (coal-tar pitch or asphalt) provides waterproofing. However, since bituminous materials have relatively little strength and are subject to degradation when exposed to the weather, they need reinforcement in the form of felts or fabrics and a protective top surface. The membrane usually is installed over insulation but it can be applied directly to the structural roof deck. In the United States, bituminous membrane BURs are installed following prescriptive specifications for materials and assembly techniques.

The waterproofing agent is the most important membrane element in BUR. If the bitumen had enough fire resistance, rigidity, strength, stability, and weathering resistance, a roof could be constructed of this material alone. However, since bitumens are viscoelastic, the other elements are essential. Felts stabilize and reinforce the membrane (much like steel reinforcement in concrete) and provide about 90 percent of the membrane's tensile strength. In hot weather, the felts keep the bitumen from flowing; in cold weather, they help it resist shrinkage stresses.

The bitumens are protected from weathering by aggregate surfaces or coatings applied over the membrane. Surfaces protect the bitumen from solar radiation which, through a combination of heat and photochemical oxidation, accelerates bitumen embrittlement and cracking. Mineral aggregate surfacing forms a fire-resistant skin that inhibits flame-spread; it also protects the membrane from abrasion due to rain, wind, and foot traffic. This type of surface prevents deterioration caused by acid mists condensing on a roof in industrial areas, acts as a ballast that offers some resistance to wind uplift, and protects against the impact of hailstones. Coatings can provide reflective surfaces and, in some cases, fire resistance as well. However, they generally require periodic renewal.

The criteria for judging bituminous membrane performance have been largely based on observation and experience. Systems that "worked" have persisted while many that had problems have been withdrawn from the market.

Single-Ply Roofing

Modified Bitumen Roofing Membranes

These roofs are composite sheets consisting of bitumen and modifying compounds, such as styrene-butadiene-styrene (SBS) and atactic polypropylene (APP). The membranes are reinforced with plastic films, polyester mats, glass fibers, or felts or fabrics which may be laminated to one surface or embedded within the modified bitumen. The membranes may be further protected with liquid coatings, metallic laminates, ceramic granules, or mineral aggregate to enhance ultraviolet (UV) and fire resistance. Modified bitumen membranes can be loosely laid and ballasted, partially or fully adhered with cold adhesive or hot asphalt, or attached by heating the membrane with a torch. Other modified bitumen roofing systems are self-adhering with a pressure-sensitive backing. Modified bitumen membranes range in thickness from 1 to 4 mm (40 to 160 mils).

Thermoplastic Roofing Membranes

Materials comprising these roofs can undergo structural change upon heat application. They can be softened repeatedly with heat and will harden when cooled. Temperatures above the range of normal conditions are required to soften the material.

Polyvinyl chloride (PVC) membranes are produced from thermoplastic PVC modified with stabilizers and plasticizers. PVC membranes can be nonreinforced or reinforced with glass fibers or polyester fabrics and are produced by calendering, extrusion, or spread-coating. PVC roofing systems can be installed fully adhered, loosely laid and ballasted, partially adhered, or mechanically fastened. PVC membranes are not compatible with bituminous materials. The seams are formed by heat or chemical welding, and thickness ranges between 0.8 and 1.2 mm (32 and 48 mils), although one accepted standard specifies a minimum thickness of 1.14 mm (45 mils).¹

Elastomeric Roofing Membranes

Elastomerics have rubber-like properties in that they can be deformed under stress and return to their original shape when the stress is removed. This group of materials can be separated into two distinct types based on the way their molecules are linked: vulcanized and nonvulcanized.

Vulcanized Membranes. These materials are cured during the manufacturing process, causing their molecular linkages to become permanent and unchangeable upon exposure to either chemicals or heat. Curing is done by cross-linking, which is the permanent bonding together of molecules in a chain. Vulcanization is the cross linkage of a molecular chain as a result of a sulfur bond. The seams of vulcanized elastomers can be sealed only through the use of adhesives. The two most common types of vulcanized membranes are ethylene propylene diene terpolymer (EPDM) and neoprene.

Although it is possible to formulate nonvulcanized EPDM membranes, most of these roofs use a vulcanized material. EPDM membranes usually are manufactured by a calendering process that draws a semicooled compound through a series of rollers to achieve a uniform thickness. The final product is usually black. These membranes can be installed fully adhered, loose-laid and ballasted, partially adhered, or mechanically fastened. The seams are joined with either contact adhesives or a splicing tape. Sometimes a topcoat of liquid Hypalon* (chlorosulfonated polyethylene [CSPE]) with sand is used for fire resistance. EPDM membranes range in thickness from 0.75 to 1.5 mm (30 to 60 mils).

Neoprene is formulated from polymers of chloroprene and is usually manufactured by calendering. Neoprene is available with or without reinforcement. These membranes may be installed with mechanical fasteners or they can be loose-laid and ballasted or fully adhered. Quick-setting, high-strength adhesives are used to attach the membranes to each other or to the substrate. A topcoat of liquid Hypalon with sand often is used to provide fire resistance and when a stable, uniform color is desired. Neoprene ranges in thickness from 0.8 to 1.5 mm (32 to 60 mils).

¹American Society for Testing and Materials (ASTM) Standard ASTM D 4434-85, "Standard Specification for Poly (Vinyl Chloride) Sheet Roofing," *ASTM Annual Book of Standards* (ASTM, 1986).

*Hypalon is a registered trademark of E.I. DuPont de Nemours and Co.

Nonvulcanized Membranes. These elastomerics are not cured during manufacture. Nonvulcanized membranes are self-curing upon exposure to the weather. These membranes include CSPE, chlorinated polyethylene (CPE), polyisobutylene (PIB), and nitrile alloy (NBP). (Some CPE, PIB, and NBP roofing manufacturers claim these products remain in the uncured state.)

CSPE sheets are usually calendered and reinforced with a polyester scrim (a reinforcing fabric) or laminated with a felt or fiber backing. These membranes can be installed with mechanical fasteners, or they can be fully adhered or loosely laid and ballasted. Upon exposure to weather, the nonvulcanized product cures (i.e., cross-linking occurs). Before the curing process occurs, the seams can be formed by either solvent- or heat-welding. After curing, adhesives must be used to seal the seams. This product is available in many colors and is adaptable to a variety of roof shapes and substrates. CSPE ranges in thickness from 0.75 to 1.5 mm (30 to 60 mils).

CPE membranes are produced as uncured elastomers by calendering or extrusion. CPE membranes laminated with polyester reinforcement can be installed fully adhered or mechanically fastened; nonreinforced sheets can be loose-laid and ballasted. CPE is resistant to bitumen, so it can be installed directly over existing asphalt or coal-tar pitch roofs. These membranes usually are light gray or white but are also available in a variety of colors. The sheets are joined by chemical- or heat-welding as well as by adhesives. Thicknesses range between 0.8 and 1.2 mm (32 and 48 mils).

PIB is an elastomeric compound made of polyethylene, isobutylene, and other polymers, and usually is manufactured by extrusion. The 1.5-mm (60-mil) PIB membrane usually is laminated to a 1.0-mm (40-mil) fleece backing with an unbacked sealing edge for side laps. End laps are sealed with PIB tape. Most PIB roofing systems are installed partially attached, but they can be loose-laid and ballasted or fully adhered. PIB is compatible with asphalt, but is not resistant to substances containing coal tar. The PIB system is 2.5 mm (100 mils) thick, including a 1.5-mm (60-mil) membrane and the 1.0-mm (40-mil) backing.

NBP membranes are compounded from PVC, butadiene-acrylonitrile copolymers, nonvolatile polymeric plasticizers, and other proprietary ingredients. The membranes usually are reinforced with polyester. These roofs are sensitive to aromatic hydrocarbons, but are resistant to most other chemicals. Most NBP roofing systems are installed with mechanical fasteners, but ballasted systems are also possible. Hot air is used to adhere the membrane to itself to form the seams. NBP membranes range in thickness between 0.75 and 1.0 mm (30 and 40 mils).

3 SURVEY OF EXISTING CRITERIA AND TESTS

Two basic approaches can be used to evaluate a roofing system: (1) theoretical and (2) performance-based. The theoretical approach is based on mathematical modeling which predicts how roof system components will interact. These models make assumptions based on known material properties combined with the effects of thermal, hygric, and mechanical behavior of the roofing system. The performance approach involves "real world" testing, in which desirable properties (called "criteria") are stated for a roof; these criteria can be judged as met or failed based on laboratory tests. This study focuses exclusively on the performance approach.

Criteria and Testing in the Field

Many roofing companies were contacted to learn if they have established procedures for evaluating their products. According to most reports, manufacturers test a new roofing system's performance before it is marketed. They use standard tests accepted by professional organizations such as the American Society for Testing and Materials (ASTM) when appropriate tests are available. The test results form the basis for the manufacturer's product description.

Often no standard tests are available and new testing procedures and acceptance criteria must be developed. These tests may be developed by industry associations alone or acting jointly with Government standards-writing agencies such as the National Bureau of Standards (NBS) and the Canadian General Standards Board (CGSB). These standards organizations do not investigate every new roofing system; they will look at a particular type of roof when another organization requests their help and when funding allows them to participate.

Standards also may be developed by organizations sponsored by insurance companies. Two such examples are Factory Mutual Engineering and Research Corp. (FM), Norwood, MA, and Underwriters Laboratories (UL), Inc., Northbrook, IL.

When new performance tests are developed, they must be designed to be repeatable and reproducible. "Repeatability" means that similar results can be obtained from a test on repeated occasions in the same laboratory. "Reproducibility" means that similar results can be obtained from tests run in a similar way in different laboratories. Before test procedures are accepted by professional organizations, they are subjected to a series of "round-robin" tests in several laboratories to confirm their reliability. They are published only after this testing, and even then each published procedure must state the precision of results generated in the tests. Most organizations also require that every procedure be reviewed periodically so that any necessary changes can be made.

Building owners depend on professionals within the construction industry such as architects, engineers, and roofing contractors for advice on which roofing system will best meet their needs. These professionals rely on "track records" of the available roof systems. If the track record is relatively short, as with many new systems, the manufacturers' literature must be analyzed to predict the characteristics of each system. Most product literature describes the results of various tests performed at the factory. After a product is selected, the professional specifies how the material is to be applied. However, not all building professionals are skilled at interpreting results of the manufacturers' test data and not all of these data are presented in a way that is useful to the professional.

Literature Review

During the early 1970s, the NBS began research aimed at identifying performance characteristics in an attempt to promote more satisfactory results from BUR. One important outcome of this research was that it showed a serious lack of test methods for evaluating roof systems. The other landmark result of the NBS research was the publication of NBS BSS 55, *Preliminary Performance Criteria for Bituminous Membrane Roofing*, in 1974. This document identified 20 attributes believed to have significant impact on the total performance of an installed BUR system. These performance criteria are:

- Tensile strength
- Thermal expansion
- Flexural strength
- Tensile fatigue strength
- Flexural fatigue strength
- Shear strength
- Impact resistance
- Notch tensile strength
- Moisture effects on strength
- Creep
- Ply adhesion
- Abrasion resistance
- Tear resistance
- Pliability
- Permeability
- Moisture expansion
- Weather resistance
- Wind uplift resistance
- Fire resistance
- Fungus attack resistance.

Although NBS BSS 55 was a major achievement and the first step in defining performance criteria, it identified preliminary performance criteria only for bituminous membrane roofing; therefore, not all criteria apply to other types of roofing. Also,

setting limits on a particular characteristic, such as tensile strength, will not necessarily ensure satisfactory in-service performance for all types of roofing systems.

No other published research describes performance criteria for either BUR or single-ply roofing. Several related studies are in progress (see Appendix A), but no comprehensive report on performance criteria has been published. Because of the lack of information, efforts in this study turned toward developing a working outline that identifies areas for which guidance is needed. Meaningful performance criteria might incorporate many of the same parameters outlined in the next chapter; however, verification of these criteria for single-ply roofing will require extensive research. In addition, some criteria cannot be judged realistically because there are no appropriate test methods. In those cases, tests need to be developed. Appendix B lists tests advocated by some international organizations; with the exception of the ASTM standards, most of these tests have not been approved in the United States.

4 CRITERIA FOR SINGLE-PLY ROOFS: A WORKING OUTLINE

The sparse information available can be organized into a rough outline to highlight specific areas where research and development are needed. It is beyond the scope of this work to conduct the exhaustive studies that will be required to fill in the missing information; however, the findings in this investigation may serve as a guide to other researchers in the field.

Performance criteria and their related test methods can be divided into two groups: in-application and in-service. In-application criteria and testing are involved with the various problems in handling the roofing components and installation. Thus, the period from a roof's manufacture to its complete installation is considered to be the in-application phase. In-service performance criteria and tests deal with everything related to the roofing system after it is in place.

In-Application Criteria and Testing

Because many of the new roofing systems require handling and installation methods that are completely different from those of conventional BUR, they present a whole new set of potential problems. Furthermore, if the roofing system sustains damage during application, in-service performance criteria become meaningless. The performance criteria and test methods described in this section are based on proposals by several standards organizations. The tests are designed to help evaluate the resistance of the materials to damage during installation and handling between the point of manufacture and the job site. Some of the criteria do not have test procedures; also, some apply to only one type of roofing system whereas others could apply to all systems. Tests that have been developed to evaluate in-service conditions have not proved applicable to evaluating application-related criteria.

Unrolling Membranes in Cold Weather

Unrolling a single-ply roof membrane in cold weather could cause adverse reactions such as splitting or cracking. Two methods are used to assess this potential--a full-scale test and a representative test. In the full-scale test, a complete roll of membrane material is unrolled in a large chamber which has been cooled to the required temperature. The representative test evaluates the material by bending a small sample over a mandrel; both the sample and mandrel are precooled.

Handling Membranes in Warm Weather

Excessively warm temperatures can weaken various membranes to a point where they puncture easily, will not unroll, or are unworkable. At present, there are no test methods or standards for determining how a membrane performs under these conditions.

Curing Time of Adhesives

The adhesive's curing time should not be too slow or too fast. If it is too slow, there is a danger of slippage as workers walk over the sheets. If the curing time is too fast, there might not be enough time to reposition the sheets to achieve proper lap coverage. No tests were identified for evaluating adhesives' curing time.

Puncture Resistance

Conditions at most construction sites require that a membrane resist puncture from sharp objects. Static tests for puncture resistance are mentioned in Appendix B for in-service applications, but no test considers the potential for puncture as the membrane is being unrolled during installation. These tests simulate an object being dropped onto the membrane or a steadily increasing load being applied, but do not evaluate an entire roll of material passing over a rock or nail.

Resistance to Puncture From Aggregate (Ballast) Due to a Wheelbarrow Load

During the process of spreading aggregate for a ballasted roofing system, a loaded wheelbarrow often will run over the aggregate laying on the membrane. It is also possible that a loaded wheelbarrow will be turned 90 degrees or more over aggregate on the membrane, subjecting the membrane to a combination of aggregate being ground into it and abrasion from the wheelbarrow. Several organizations are working on a test for membrane resistance to this load.

In-Service Criteria

The following list of in-service performance criteria is based on similar criteria for BUR. Methods for evaluating some of the criteria are under development (e.g., by the organizations listed in Appendix A). No such tests have been approved in the United States to date. Tables 1 and 2 list limits for some of these criteria as proposed by the Norwegian Building Research Institute in 1983.

Tensile Strength

The membrane should not act as a structural member, but it must be strong enough to resist the internal and external tensile forces imposed on it under service conditions.

Thermal Expansion, Contraction

Roof membranes must be strong enough to withstand the rapid temperature changes to which they may be exposed.

Flexural Strength

The membrane must have flexibility to resist bending and crushing from forces such as those caused by wind, moving wheel loads, and foot traffic.

Tensile Fatigue Strength

The membrane must resist repeated flexural stresses from bending due to wind uplift, vibrations, wheel loads, and foot traffic.

Shear Strength

The membrane should be strong enough to resist vertical punching shear. Also, horizontal shear should have no effect on membrane integrity.

Table 1
Proposed Requirements for Category I Roofs*

Parameter	Requirement	Comment
Tensile strength	8 N/mm ²	950 N/50 mm for reinforced system
Elongation at break	200%	10% for reinforced system
Low temperature flexibility	-30°C	No cracks
Water vapor		Dependent on vapor retarder and climate
Thermal expansion	<0.5%	Perimeter attachment is required if >0.5%
Resistance to puncture	150 N	250 N for exposed membranes
Wind uplift resistance	>1000 Pa	Mechanical fasteners required
Tear resistance	180 N	For mechanically attached systems
Fire resistance	Passes	For exposed membranes
Accelerated weathering:		
Shrinkage	<1.0%	At 48 weeks' aging
Flexibility	-20°C	
Air +70°C:		
Shrinkage	<0.5%	After 2 weeks
Weight loss	<2.0%	
Flexibility	-20°C	
Water +50°C:		
Shrinkage	<0.5%	After 8 weeks
Flexibility	-20°C	

*Category I roofs are those which can be inspected and are mechanically attached, adhered, or ballasted with gravel. Source: Einar M. Paulsen, *Test Program Proposed Requirements on Membranes for Roofs of Category I&II* (Norwegian Building Research Institute, 1983).

Table 2
Proposed Requirements for Category II Roofs*

Parameter	Requirement	Comment
Membrane		
Tensile strength	8 N/mm ²	
Elongation at break	200%	
Low temperature flexibility	-30°C	No cracks
Thermal expansion	<0.5%	Perimeter attachment is required if >0.5%
Resistance to puncture	150 N	Membrane on insulation
Root resistance	No perforation after 8 weeks	For garden roofs
Air +70°C:		
Shrinkage	<0.5%	After 2 weeks
Weight loss	<6%	
Flexibility	-20°C	
Water +50°C:		
Shrinkage	<0.5%	After 8 weeks
Weight loss	<6%	
Flexibility	-20°C	
Seams or Laps		
Strength	80% of membrane	For heat-welded seams
	70 N/25 mm with 50 mm overlap joint	Adhered lap joints

*Category II roofs are those for light or heavy traffic, gardens, and all inverted applications.

Wind Uplift

The membrane must be designed to be fastened in a way that prevents it from being loosened and blown away by wind. A specific test for this criterion is described in Chapter 5.

Notch Tensile Strength

The membrane's tensile strength should not change significantly if reinforcement sheets sustain damage.

Creep

Membranes should be able to withstand stresses over long periods of time without permanent deformation due to creeping.

Ply Adhesion

The composite action of built-up systems is dependent on the adhesion of plies to each other by means of adhesive in between them. Blistering is reduced by eliminating voids between plies.

Abrasion

The membrane should resist wearing away due to objects being dragged across the roof, wind-blown elements, and foot or wheel traffic.

Tearing

The membrane should resist tearing that will destroy its watertightness. This requirement includes resistance to further tearing when the membrane is already torn in some place.

Weather

The membrane must not be adversely affected by solar radiation, moisture, and pollutants. In addition, it must remain watertight upon impact from hail. The membrane should remain flexible (pliable) in all types of weather, including extremely hot and cold temperatures.

Seam Strength

The membrane seams must be able to withstand tensile stresses.

Thermal Shock Resistance

The membrane must resist large (28 to 56°C [50 to 100°F]) and rapid (within a few hours) temperature changes.

Ductility

The membrane must be ductile; it should be able to bend and return to its original shape.

Effects of Moisture

The membrane must be impermeable to all types of moisture, including water vapor. It also must resist moisture absorption under standing water to prevent leaks and permanent elongation. Sudden changes in moisture conditions can produce stresses in the membrane that lead to reduced strength; the roof must be designed to withstand these variations.

Load-Strain

A membrane reacts to load-strain depending on how the two properties work together. It is difficult to interpret load-strain in terms of performance under service conditions.

Compressive Strength

A membrane must remain waterproof during and after the application of compressive loads.

Effects of Microorganisms and Fungus

The roofing membrane must not permit the growth of microorganisms and must resist the effects of fungus attack.

Aging

The membrane must be able to withstand the effects of exposure over time. Changes in weight and elongation properties at elevated temperatures indicate poor aging ability. Other tests that can be used to evaluate a membrane's ability to retain its properties over time include:

- Air at 70°C (ASTM D 573)*
- Accelerated weathering (ASTM G 26)
- Water at 50°C (ASTM D 2126)
- Xenotest (DIN 53387)
- Ozone (ASTM D 1149)
- Microbial resistance (ISO D15846)
- Volatile loss (ASTM D 1203)
- Effects of sulfur dioxide (DIN 53377).

Color Stability and Reflectivity

Some roofing membranes are selected for their ability to reflect solar radiation. The membrane's reflectivity must be retained despite dirt and/or color change.

*Complete references for these tests are listed in Appendix B.

Combined Action of UV, Heat, and Water

The membrane must be able to withstand the effects of ponding water combined with direct sunlight without damage to its integrity.

Leakage at Joints

All joints must be fully bonded and sealed to prevent water penetration.

Crack Bridging

The membrane must resist stresses and span the cracks caused by slowly moving joints in a substrate.

Peel Strength

The seams must resist peeling under stresses such as those caused by wind.

Granule Embedment

When membranes are covered with mineral aggregate, the granules must remain adhered upon exposure to foot traffic, wind, and rain.

Aggregate Penetration

The membrane must resist punctures caused by normal roof conditions such as aggregate penetration.

Roots

The membrane must resist penetration by plant roots. This requirement is especially important for terraces, gardens, and inverted roofs. It also applies to roofs in rural environments where blowing seeds are prevalent.

Fire Resistance

The membrane should have a specified resistance to fire. The test for this criterion is described in Chapter 5.

5 TEST METHODS THAT EVALUATE ENTIRE ROOF SYSTEMS

Most tests for single-ply roofing analyze only one element of the system such as the membrane or insulation, but not the membrane, insulation, and supporting deck together. However, a roof is composed of several elements operating together as a system to protect the building. Thus, it is important to consider some criteria using a systems approach. Three criteria have been established for evaluating the entire roofing system: fire resistance, wind uplift resistance, and impact resistance.

Fire Resistance

The most important standard-setting organizations for fire and wind-uplift resistance are UL and FM. Both organizations classify roof assemblies for fire and wind-uplift resistance for many U.S. insurance companies as discussed in Chapter 3. UL and FM maintain laboratories for testing manufacturers' building products; those satisfying their standards are "listed" and construction companies use the results to develop specifications and recommendations. UL standards are also the basis for building code requirements covering fire resistance of BUR assemblies.

Fire Hazards

Fire hazards that concern building code officials and insurance companies are classified broadly as:

- External, above-deck fire exposure
- Internal, below-deck fire exposure.

UL criteria and tests are generally the basis for external fire resistance requirements. Criteria for internal fire resistance are the limitation of flame spread and a time-temperature rating.

External Fire Resistance

Two critical parameters are considered in assessing external fire resistance: (1) surface burning or propagation of the fire along the roof and (2) penetration of the fire into the deck structure. A flame-spread test is used to evaluate the first criterion; the burning brand test and intermittent flame tests are used to evaluate fire penetration. The test methods and acceptable criteria are well established and used by the industry to rate roof systems as A, B, or C according to their fire resistance.

Internal Fire Resistance

In 1953, FM and UL conducted tests on a 6 by 30 m (20 by 100 ft) test building. These tests confirmed the hazard of placing large quantities of bitumen directly on a steel deck with combustible wood fiber insulation. The results demonstrated that a hot bituminous mopping which is thick enough to bond the wood fiber insulation cannot be part of a fire-resistant steel-deck roof system.

Flame-Spread Test. To satisfy building code and insurer requirements, a roof system must resist fire from within the building. The chief safeguard required to control internal fire spread in a roof is the limitation of flame spread along the roof's underside. Based on results of the fire tests just described, a steel-deck roof with 2.5-cm

(1-in.), mechanically anchored, plain vegetable fiberboard insulation and four-ply, aggregate-surfaced BUR membrane became the standard roof construction with which other assemblies are compared for both UL and FM ratings. In the modified standard UL723,² the test roof assembly forms the top of a test tunnel, with twin gas burners delivering flames against its soffit. The gas supply and other variables are adjusted until the furnace produces a flame-spread rate of 6 m (19.5 ft) in 5.5 min on select-grade, red-oak flooring. To qualify as "acceptable" in the tunnel test, a roof must not have a flame spread on its underside of more than 3 m (10 ft) during the first 10 min and 4.3 m (14 ft) during the next 20 min. In the 6 by 30 m (20 by 100 ft) test building, an acceptable roof assembly must have a flame spread of no more than 18 m (60 ft) from the fire end of the test structure during the 30-min test.

FM's classification of resistance to interior fire divides roof assemblies into two basic categories: sprinklered and unsprinklered. Roof assemblies not requiring sprinklers include:

- Class I steel-deck assemblies
- Noncombustible decks (e.g., concrete, gypsum, asbestos cement, and preformed structural mineralized wood fiber)
- Wood decks treated with fire-retardant, inorganic salts that limit flame spread to 7.6 m (25 ft) or less.

Roof assemblies that require sprinklers include:

- Class II steel-deck assemblies
- Combustible decks (untreated wood).

Time-Temperature Ratings.

ASTM E 119, "Fire Tests of Building Construction and Materials," describes methods of measuring the performance of various building assemblies including roof constructions under fire exposure conditions. The standard describes exposure to fire of controlled extent and severity. The performance is defined as the period of resistance to standard exposure elapsing before the first critical point in behavior is observed. The performance is expressed as "2-hour," "6-hour," "½-hour," etc., and gives an evaluation of the ability of the assembly to contain a fire and retain its structural integrity. A sample of the construction (at least 180 square feet) is installed in the combustion chamber of the test equipment and loaded to simulate maximum loading condition. Thermocouples installed on the assembly record the temperatures at various points in the assembly as the temperature of the chamber is increased following the standard curve described in the procedure. The test is continued until either the assembly fails or a period equal to the desired time has been reached. E 119 also describes a method of determining the performance of protective membranes in roofs.

²ASTM E 84, "Test Method for Fire Hazard Classification of Building Materials," *ASTM Annual Book of Standards* (ASTM, 1986).

Wind Uplift

Wind uplift causes stresses at all interfaces of a roof system--between framing members and deck, deck and vapor retarder, vapor retarder and insulation, and insulation and membrane.

The Rubber Manufacturers Association (RMA) Roofing Council issued a wind design guide for roofing systems in 1985. The guide included design considerations for all types of roofs including built-up, loose-laid, fully adhered, mechanically attached, etc. While the guide is basically prescriptive in nature, it does include a test method for determining the resistance of roof edge terminations on elastomeric membranes. A minimum resistance of 75 lb lin ft is recommended and a procedure is described using a tensile testing machine to determine the load required to allow the membrane to come free of the roof edge termination.

FM tests roofs on steel decks only. To qualify for an I-60 rating, the roof-deck must withstand a minimum of 2872 Pa (60 psf) pressure for 1 min and show no evidence of bond failure between components and no delamination of the insulation.

The 2872-Pa (60-psf) value was derived as follows: average wind velocity seldom exceeds 55 km/hr (88 mph), which corresponds to 957 Pa (20 psf) static pressure. Converted to uplift, that pressure produces 30-psf uplift (1.5 shape factor x 20 psf static pressure). A safety factor of 2 raises the test load to 2872 Pa (60 psf). If winds exceed 55 km/hr (88 mph), roofing components must meet the I-90 uplift test as listed in FM's annual *Approval Guide*.

Impact Resistance

Dynamic Indentation

The standard ASTM test method for dynamic indentation is D 3746, "Comparative Impact Resistance of Bituminous Roofing Systems." In this test, specimens of a complete roof system (insulation and membrane with top surfacing) are divided into four sections or quadrants. Each quadrant is then subjected to an impact load applied by dropping a standard weighted missile from a predetermined height. The damage to the membrane is assessed by visual examination of the felts after the bitumen is removed from the sample by solvent extraction. The effect of temperature can be studied by running the test at variable temperatures in an environmental chamber. Although the test was developed for BUR systems, it can also be useful for comparing the impact resistance of single-ply systems.

Static Indentation

The standard ASTM test method for static indentation is E 719.³ This method evaluates the exposed surface of representative construction using a testing machine in which a calibrated point load is applied in increasing increments and the corresponding indentation and set are measured. This test provides data that can be used to evaluate the relative indentation characteristics of exposed building surfaces subjected to

³ASTM E 719, "Test Method for Indentation of Building Materials' Surfaces Under Concentrated Loads as a Measure of Serviceability," ASTM Annual Book of Standards (ASTM, 1986).

concentrated loading. It is not intended for measuring the structural performance of a material or its supporting elements, but is used to examine properties affecting serviceability.

Both FM and UL conduct laboratory wind uplift tests and publish lists of approved roof-deck assemblies. FM publishes its approved list annually in the *Approval Guide* under "Building Materials and Construction." UL lists roof-deck assemblies as Class 30, 60, or 90, based on successful resistance to 2154 Pa (45 psf), 3591 Pa (75 psf), or 5027 Pa (105 psf), respectively, total negative pressure in the UL uplift test. The UL test features a sophisticated apparatus designed to simulate actual wind loading on a roof system.

6 CONCLUSIONS AND RECOMMENDATIONS

Performance criteria and test methods for comparing different single-ply roofing products have been investigated. Almost no guidance is available to help military construction specifiers choose among these new roofing systems. The only criteria accepted in the United States apply to the roof as a whole and cover resistance to fire, wind uplift, and impact. Some international standards organizations are in the process of developing more criteria and tests, but none to date have been accepted by U.S. standards institutions.

Due to the lack of information, specific performance criteria and test methods cannot be recommended for evaluating parameters other than the three listed above. However, this investigation has served to identify areas that require further study; there is a need for basic research and development using a performance approach to establish criteria and tests for roof systems. This report has described some very general criteria to provide a working outline for other researchers. It is recommended that standards be developed for accurate prediction of both in-application and in-service performance of unconventional roofs. Until comprehensive results are available, specifiers will have to rely on the accepted standards that deal with individual elements of a roofing system such as membrane strength and flexibility; these standards usually prescribe an acceptable range of values for mechanical and physical properties.

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- Method of Assessment and Testing (MOAT) No. 27, *General Directive for the Assessment of Waterproofing Systems* (European Union of Agreement [UEAtc], January 1983).
- Midwest Roofing Contractors Association (MRCA) Standard ME-20, *Recommended Performance Criteria for Elastomeric Single Ply Roof Membrane Systems* (November 1982).

Minimum Requirements for Fabric-Reinforced Black EPDM Rubber Sheets for Use in Roofing Applications (Rubber Manufacturers Association [RMA], 1984).

Minimum Requirements for Fabric-Reinforced Black Polychloroprene Rubber Sheets for Use in Roofing Applications (RMA, 1984).

Minimum Requirements for Non-Reinforced Black EPDM Rubber Sheets for Use in Roofing Applications (RMA, 1984).

MOAT No. 28, *General Directive for the Assessment of Roof Insulation for Flat and Sloped Roofs* (UEAtc, December 1983).

MOAT No. 29, *Directives for the Assessment of Roofing Systems Using PVC Sheets Without Reinforcement, Loose-Laid Under Heavy Protection and Not Compatible With Bitumen* (UEAtc, April 1984).

MOAT No. 30, *Special Directives for the Assessment of Reinforced Homogeneous Waterproof Coverings of Atactic Polypropylene (APP) Polymer Bitumen* (UEAtc, August 1984).

MOAT No. 31, *Special Directives for the Assessment of Reinforced Homogeneous Waterproof Coverings of Styrene-Butadiene-Styrene (SBS) Elastomer Bitumen* (UEAtc, August 1984).

MRCA MB-30, *Recommended Performance Criteria for Modified Bitumen Roof Membrane Systems* (November 1983).

MRCA MP-10, *Recommended Performance Criteria for PVC Single Ply Roof Membrane Systems* (November 1983).

Paulsen, Einar M., *Test Program Proposed Requirements on Membranes for Roofs of Category I&II* (Norwegian Building Research Institute, 1983).

Performance Criteria for New and Aged Polyurethane Roofs (Urethane Foam Contractors Association, February 1986).

Preliminary Performance Criteria for Bituminous Membrane Roofing, NBS Building Science Series 55 (U. S. Department of Commerce, November 1974).

Roofing Materials and Guide (NRCA, February 1984).

Standards for Safety Materials for Built-up Roof Coverings (Underwriters Laboratories [UL], Inc., October 1983).

UL 55B, *Standards for Safety Class C Asphalt Organic Felt Sheet Roofing and Shingles* (UL, Inc., October 1983).

Wind Design Guide for Roofing Systems (RMA/IPR-4, 1985).

APPENDIX A:

PERFORMANCE STUDIES IN PROGRESS

The areas under study by various standards organizations are summarized. More information can be solicited by writing directly to these organizations (addresses are listed at the end of this appendix). Specific tests being investigated are summarized in Appendix B.

Tokyo Institute of Technology (Japan)

Current work is similar to that of the European Union of Agreement (UEAtc) and includes:

1. Behavior in fire
2. Resistance to pull-off under suction
3. Resistance to peel (for single-layer systems)
4. Resistance to water pressure
5. Resistance to thermal shock
6. Dimensional stability
7. Restrained shrinkage (roof membrane)
8. Resistance to cyclic movement
9. Resistance to static indentation
10. Resistance to dynamic indentation
11. Permeability to water vapor
12. Resistance to leakage at joints
13. Tensile strength (shear) of joints
14. Behavior of joints due to aging upon exposure to elevated temperatures
15. Behavior of joints due to aging upon exposure to water
16. Resistance to plant roots
17. Onsite tests related to waterproofing:
 - Resistance to tearing

- Flexibility at low temperatures
- Unrolling test at low temperatures.

Norges Byggestandardsiseringsrad (NBI) (Norway)

NBI has developed the following criteria and tests:

- NS 3047 - Felts, films and rubber for buildings.
Designations and quality requirements.
- NS 3048 - Felts, films and rubber for buildings.
Test methods.
- NS 3440 - Roofs, load bearing units. Dimensions.
- NS 3905 - Fire resistance tests. Roof coverings.
Resistance to spreading fire.
- NS 3919 - Classification in fire resistance and
reaction to fire. Building elements,
coverings, surfaces and materials.

The Rubber Manufacturers Association (RMA) (USA)

RMA is funding a study in conjunction with ASTM to evaluate three different EPDM membranes (nonfabric reinforced "white," nonfabric reinforced "black," and a known control material) using five weathering tests (xenon arc weatherometer, carbon arc weatherometer, fluorescent UV-condensation apparatus, South Florida direct inland weathering, and the Equatorial Mount With Mirrors for Acceleration Plus Water Spray [EWMAQUA] method).

In addition to this work, RMA has developed minimum requirements for nonreinforced and reinforced black EPDM and reinforced polychloroprene rubber sheets used in roofing applications; the properties they have included are:

- Thickness
- Ozone resistance
- Linear dimensional change
- Heat aging (tensile, elongation, and tear resistance)
- Water absorption
- Factory seam strength
- Tensile strength
- Elongation

- Tensile set
- Tear resistance
- Brittleness point
- UV weathering test (still under study).

National Roofing Contractors Association (NRCA) (USA)

Every 6 months (February and August) the NRCA publishes the *Commercial, Industrial and Institutional Roofing Materials Guide*. This guide is continually updated with the latest information on roofing systems and insulation. It includes an index of roofing manufacturers and their products. This guide lists 25 tests considered important in assessing performance criteria. In addition, the NRCA has been working to develop performance criteria. The evaluation systems have not yet been published.

European Union of Agreement (UEAtc)

UEAtc is an institution composed of representatives from most countries in Europe. UEAtc prepares directives for roofing products and systems. Its most recent *Methods of Assessment and Testing (MOATs)* are Nos. 30 and 31 for modified bitumen roofing. No. 30 covers atactic polypropylene (APP) and No. 31 discusses styrene-butadiene styrene (SBS) modified bitumen roofing.

National Research Council of Canada (NRCC)

NRCC studies different roofing systems and their properties. Current tests involve modified bitumen roofing products (both SBS and APP). NRCC plans to evaluate the following criteria:

1. Puncture resistance (membrane and systems)
 - Dynamic impact
 - Static impact
2. Heat aging (membrane only)
 - Dimensional change
 - Weight change
 - Loss of flexibility
 - Heat resistance
3. Dimensional stability (membrane only)
4. Resistance to cyclic movement (membrane and system)

5. Low-temperature flexibility (membrane only)
6. Heat resistance (membrane and system)
7. Granular embedment and coverage (membrane)
8. Adhesion (membrane and system)
9. Tear strength (membrane and system)
10. Tensile strength (membrane and system)
 - Elongation at break
 - Load-strain product.

Ruberoid Building Products, Ltd. (GB)

This company is working with UEAtc. Projects include:

- Roof with rubber-modified coatings
- Roof with atactic polypropylene-modified coatings
- Single-ply membranes.

Canadian General Standards Board (CGSB)

The current CGSB series of membrane roofing standards include:

37-GP-52M - Roofing and waterproofing membrane, sheet-applied, elastomeric.

37-GP-54M - Roofing and waterproofing membrane, sheet-applied, flexible polyvinyl chloride.

37-GP-50M - Asphalt, rubberized, hot-applied, for roofing and waterproofing.

37-GP-56M - Membrane, modified bituminous, prefabricated and reinforced for roofing.

37-GP-58M - Membrane, elastomeric, cold-applied liquid for nonexposed use in roofing and waterproofing.

37-GP-59M - Membrane, elastomeric, cold-applied liquid for exposed use in roofing.

37-GP-60M - Cold-applied liquid, elastomeric membrane system for exposed traffic-bearing area.

Factory Mutual Engineering and Research Corp. (USA)

Factory Mutual sets many roofing standards based on ASTM tests and others developed by this company. Current projects include work to update two existing standards:

- 4450 - Insulated Steel Roof Deck Construction
- 4451 - Steel Roof Deck Manufacture.

This company also has been developing a new standard, No. 4470, "Roof Coverings (Including Hail Damage)," which covers many newer roofing systems.

Midwest Roofing Contractors Association (MRCA) (USA)

The MRCA has published recommended performance criteria for PVC, elastomeric, and modified bitumen roof membrane systems. Performance criteria are recommended for each of three categories: Manufacture of Material, Application, and Field Performance. Although most criteria are common to all three material types, each has criteria identified which are specific to individual types.

Joint Committee on Elastomeric, Thermoplastic, and Modified Bituminous Roofing (CIB/RILEM)

The CIB/RILEM Joint Committee was organized in 1983 to identify and standardize criteria and test methods for producing and applying elastomeric, thermoplastic, and modified bituminous systems. The first draft of its report was completed in March 1986; it summarized and collated information and test procedures for these materials as identified to that date.

Addresses

For more information, the following organizations can be contacted directly:

American National Standards Institute (ANSI)
1430 Broadway
New York, NY 10018
(212) 354-3300

American Society for Testing and Materials (ASTM)
1916 Race St.
Philadelphia, PA 19103
(215) 299-5400

Building Research Institute (BRI)
Ministry of Construction
3-Chome, Hyakunin-cho, Shinjuku-ku
Tokyo
JAPAN

Canadian General Standards Board (CGSB)
Ottawa, Ontario K1A 1G6
CANADA

Centre Scientifique et Technique du Batiment (CSTB)
84 avenue Jean-Jaures
Champs-Sur-Marne
77428 Marne-La-Vallee cedex 2
FRANCE

Danish Building Research Institute
Postboks 119
2970 Horsholm
DENMARK

Deutsches Institut fuer Normung (DIN)
Reichpietschufer 72/76
1000 Berlin 30
GERMANY

European Union of Agreement (UEAte)
4 avenue du Recteur-Poincare
75782 Paris cedex 16
FRANCE

Federal Materials Testing Laboratory and Research Institute
for Industry, Civil Engineering, and Trade (EMPA)
Ueberlandstrasse 129
Postfach
8600 Dubendorf-Zurich
SWITZERLAND

Factory Mutual Engineering and Research Corp. (FM)
1151 Boston-Providence Turnpike
Norwood, MA 02062
(617) 762-4300

Hungarian Institute for Building Science (ETI)
P.O. Box 71
1502 Budapest
HUNGARY

International Council for Building Research, Studies,
and Documentation (CIB)
P.O. Box 299
Weena 700
Rotterdam
THE NETHERLANDS

International Standards Organization (ISO)
1 rue du Varembe
Case postale 56
1211 Geneve 20
SWITZERLAND

**International Union of Testing and Research
Laboratories for Materials Structures (RILEM)**
12 rue Brancion
75737 Paris cedex 15
FRANCE

Japanese Industrial Standards Committee (JIS)
Ministry of International Trade and Industry
3-1 Kasumigaseki
Chiyoda-ku
Tokyo
JAPAN

Midwest Roofing Contractors Association (MRCA)
1440 Commerce Bank Bldg.
1000 Walnut St.
Kansas City, MO 64106-2123
(816) 421-6722

National Bureau of Standards (NBS)
Center for Building Technology, Building Materials Division
National Engineering Laboratory
Gaithersburg, MD 20899
(301) 975-6706

National Research Council of Canada (NRCC)
Division of Building Research
Ottawa K1A30R6
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National Roofing Contractors Association (NRCA)
1 O'Hare Center
6250 River Road
Rosemont, IL 60018
(312) 318-6722

Norwegian Building Research Institute (NBI)
7034 Trondheim, NTH
NORWAY

Rubber Manufacturers Association (RMA)
1400 K Street, N.W.
Washington, D.C. 20005
(202) 682-1338

**Small Homes Council-Building Research Council of
the University of Illinois (SHC-BRC)**
1 East St. Mary's Road
Champaign, IL 61820
(217) 333-1801

Swiss Society of Engineers and Architects (SIA)
Selnaustrasse 16
Postfach
8039 Zurich
SWITZERLAND

Tokyo Institute of Technology
2-12-1 Ookayama
Meguro-ku
Tokyo
JAPAN

Underwriters Laboratories, Inc. (UL)
333 Pfingston Road
Northbrook, IL 60062
(312) 272-8800

Polyurethane Foam Contractors Division of the Society
of the Plastics Industry, Inc.
1025 Connecticut Avenue NW, Suite 409
Washington, DC 20036
(202) 822-6705

U.S. Army Construction Engineering
Research Laboratory (USA-CERL)
P.O. Box 4005
Champaign, IL 61820
(217) 352-6511

APPENDIX B:

PERFORMANCE CRITERIA TESTS

Laboratory tests used by various international organizations are listed by their relationship to performance criteria. A complete list of the standards cited appears at the end of this appendix. Acronyms are defined in **ABBREVIATIONS**.

Application-Related Criteria	ASTM	CGSB	DIN	NRCC	UEAtc
(1) Unrolling Membrane in Cold Conditions	D 746	*	16938		
(2) Handling in Hot Conditions		*	*		
(3) Curing Time of Adhesives		*			29
(4) Resistance to Puncture	*				
(5) Resistance to Puncture (Wheelbarrow)	*				

*Work in Progress

Service-Related Criteria	ASTM	CGSB	DIN	ISO	SIA	SIS	FM	UL	NBI	UEAtc
(1) Tensile Strength	D 1623 D 412 D 3105 D 882		52123 53455 53354 53504	R527						
(2) Thermal Expansion	D 1204 D 696		53377 16938						149/84 143/84	
(3) Flexural Strength	D 790									
(4) Tensile Fatigue										
(5) Flexural Fatigue			52123							
(6) Shear Strength										
(7) Wind Uplift							1-52*		92/82	
(8) Notch Tensile Strength										
(9) Moisture Effects on Strength										
(10) Creep										

Service-Related Criteria	ASTM	CGSB	DIN	ISO	SIA	SIS	FM	UL	NIBI	DEAtc
(11) Ply Adhesion	C 836 D 3409									
(12) Abrasion Resistance	C 501 D 471 D 3389									
(13) Tear Resistance	D 1938 D 2582 D 624 D 1922 D 1004		53356 53515 53363							27 29 30 31
(14) Pliability	C 836									
(15) Permeability	E 96 D 3637		53122 53515							
(16) Moisture Expansion	D 1204		16938 53377							
(17) Weather Resistance	D 1669 D 412 D 529 D 1670 G 26 D 573		16726 7864							
(18) Fungus Attack	G 21									

Service-Related Criteria	ASTM	CGSB	DIN	ISO	SIA	SIS	FM	UL	NIB	UFAtc
(19) Cold Flexibility	C 836 D 746 D 2137		53361 16938 16726						83/76	
(20) Seam Strength	D 412 D 836 D 816 D 1876 D 412 D 952			1184	280					
(21) Thermal Shock Resistance										
(22) Ductility										
(23) Resistance to Sliding										
(24) Heat Resistance			53508	188		162205				
(25) Water Resistance	D 471		53495		280					
(26) Load-Strain Properties	D 2523	37GP56M								

Service-Related Criteria	ASTM	CCSB	DIN	ISO	SIA	SIS	FM	UL	NRI	UEAIC
(27) Compressive Strength	D 1621		16938		280					
(28) Effects of Microorganisms										
(29) Aging Air at 70°C	D 573		53508						142/84	
Acc. Weath	G 26				280	162210			83/83	
Water at 50°C	D 2126				280				183/84	
Xenotest			53387							
Ozone	D 1149		53509	1431/1, 1431/2 846		162210				
Microbial Volatile Loss	D 1203									
Effects of SO ₂			53377							
(30) Color Stability & Reflectivity										
(31) Resistance to Further Tearing										
(32) Combination UV, Heat & Water										
(33) Resistance to Leakage at Joints										
(34) Hail Resistance	See (41) Below									

Service-Related Criteria	ASTM	CGSB	DIN	ISO	SIA	SIS	FM	UL	NHI	UEAtc
(35) Crack Bridging										27,29 30,31
(36) Peel Strength	D 1876 C 836 D 412									
(37) Granule Embedment										
(38) Aggregate Penetra- tion										
(39) Root Penetration			4062							
(40) Fire Resistance	E 108			846	183/2			723**	NT006	
(41) Dynamic Impact	D 3746	37GP56M		DIS7892					118/81	27,29 30,31
(42) Static Impact***	E 719 D 1048	37GP56M		DIS7892						27,29 30,31

*Work in progress.

**See Chapter 5.

***Another test to consider is Fed Test Method Std No. 101C, Test Method 2031, "Puncture Resistance."

+ISO standard on this subject is in preparation.

ASTM Standards

- C 581-83 Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass Fiber Reinforced Structures, Intended for Liquid Service
- C 836-84 Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course
- D 412-83 Test Methods for Rubber Properties in Tension
- D 471-79 Test Methods for Rubber Property--Effect of Liquids
- D 529-82 Recommended Practice for Accelerated Weathering Test of Bituminous Materials
- D 543-84 Test Methods for Resistance of Plastics to Chemical Reagents
- D 573-81 Test Method for Rubber-Deterioration in an Air Oven
- D 624-81 Test Method for Rubber Property--Tear Resistance
- D 696-79 Test Method for Coefficient of Linear Thermal Expansion of Plastics
- D 746-79 Test Method for Brittleness Temperature of Plastics and Elastomers by Impact
- D 751-79 Method of Testing Coated Fabrics
- D 790-84a Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
- D 816-82 Methods of Testing Rubber Cements
- D 836-84 Specification for Industrial Grade Benzene
- D 882-83 Test Methods for Tensile Properties of Thin Plastic Sheeting
- D 952-84 Test Method for Bond or Cohesive Strength of Sheet Plastics and Electrical Insulating Materials
- D 1004-66 Test Method for Initial Tear Resistance of Plastic Film and Sheeting (1981)
- D 1048-81 Specification for Rubber Insulating Blankets. (Contains a procedure for puncture resistance testing)
- D 1149-81 Test Method for Rubber Deterioration--Surface Ozone Cracking in a Chamber (Flat Specimens)
- D 1203-67 Test Methods for Volatile Loss From Plastics Using Activated Carbon (1981) Methods

- D 1204-84 Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperatures
- D 1242-56 Test Methods for Resistance of Plastic Materials to Abrasion (1981)
- D 1621-73 Test Method for Compressive Properties of Rigid Cellular Plastics (1979)
- D 1623-78 Test Method for Tensile and Tensile Adhesion Properties of Rigid Cellular Plastics
- D 1669-84 Method for Preparation of Test Panels for Accelerated and Outdoor Weathering of Bituminous Coatings
- D 1876-72 Test Method for Peel Resistance of Adhesives (T-Peel Test) (1983)
- D 1922-67 Test Method for Propagation Tear Resistance of Plastic Film and Thin (1978) Sheeting by Pendulum Method
- D 1938-67 Test Method for Tear Propagation Resistance of Plastic Film and Thin (1978) Sheeting by a Single-Tear Method
- D 2126-75 Test Method for Response of Rigid Cellular Plastics to Thermal and Humid Aging
- D 2137-83 Test Methods for Rubber Property--Brittleness Point of Flexible Polymers and Coated Fabrics
- D 2240-81 Test Method for Rubber Property--Durometer Hardness
- D 2523-78 Recommended Practice for Testing Load-Strain Properties of Roofing (1984) Membranes
- D 2526-80 Specification for Ozone-Resisting Silicone Rubber Insulation for Wire and Cable
- D 2582-67 Test Method for Puncture-Propagation Tear Resistance of Plastic Film and (1984) Thin Sheeting
- D 3105-79 Index of Methods for Testing Elastomeric and Plastomeric Roofing and Waterproofing Materials
- D 3389-85 Method of Testing Coated Fabrics--Abrasion Resistance (Rotary Platform, Double-Head Abrader)
- D 3409-81 Test Method for Adhesion of Asphalt Roof Cement to Damp, Wet, or Underwater Surfaces
- D 3637-84 Test Method for Permeability of Bituminous Mixtures
- D 3746-78 Test Method for Comparative Impact Resistance of Bituminous Roofing Systems

- D 4434-85 Specification for Poly (Vinyl Chloride) Sheet Roofing
- E 84-84 Test Method for Surface Burning Characteristics of Building Materials
- E 96-80 Test Methods for Water Vapor Transmission of Materials
- E 108-83 Method for Fire Tests of Roof Coverings
- E 119-83 Fire Tests of Building Construction and Materials
- E 719-80 Test Method for Indentation of Building Materials Surfaces Under Concentrated Loads as a Measure of Serviceability
- G 21-70 Recommended Practice for Determining Resistance of Synthetic Polymeric (1980) Materials to Fungi
- G 26-84 Recommended Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials (formerly E 239)

CGSB Standards

- 37-GP-50M Asphalt, rubberized, hot applied, for roofing and waterproofing
- 37-GP-52M Roofing and waterproofing membrane, sheet applied, elastomeric
- 37-GP-54M Roofing and water proofing membrane, sheet applied, flexible polyvinyl chloride
- 37-GP-56M Membrane, modified bituminous, prefabricated and reinforced for roofing
- 37-GP-58M Membrane, elastomeric, cold applied liquid for non-exposed use in roofing and waterproofing
- 37-GP-59M Membrane, elastomeric, cold applied liquid for exposed use in roofing (nontraffic bearing)
- 37-GP-60M Cold-applied liquid, elastomeric membrane system for exposed traffic bearing area

ISO Standards

- 188 (1982) Rubber, Vulcanized--Accelerated Aging or Heat-Resistance Tests
- 527 (1966) Plastics--Determination of Tensile Properties (in revision)
- 846 (1978) Plastics--Determination of Behaviour Under the Action of Fungi and Bacteria - Evaluation by Visual Examination or Measurement of Change in Mass or Physical Properties
- 1184 (1983) Plastics--Determination of Tensile Properties of Films
- 1431/1 (1980) Rubber, Vulcanized--Resistance to Ozone Cracking--Part I: Static Strain Test, With Amendment 1 (in revision)

1431/2 Rubber, Vulcanized--Resistance to Ozone Cracking--Part 2: Dynamic
(1982) Strain Test

DIS7892 Impact Bodies--Impact Resistance of Vertical Building Elements (Draft
International Standard--DIS)

DIN Standards

4062 (1978) Cold Processable Plastic Jointing Materials for Sewer Drains; Jointing
Materials for Prefabricated Parts of Concrete, Requirements, Testing and
Processing

7864 (1984) Sheets of Elastomers for Waterproofing; Terms of Delivery

16726 (1984) Plastic Roofing Sheets and Plastic Sheets for Waterproofing; Test
Methods

16938 (1984) Plastic Sheets for Waterproofing Made of Plasticized Polyvinyl Chloride
(PVC-P), Not Compatible With Bitumen; Requirements

52123 (1985) Testing of Bitumen and Polymer Bitumen Sheeting

53122/1 Testing of Plastic Films, Elastomer Films, Paper, Board and Other Sheet
(1974) Materials; Determination of Water Vapour Transmission Rate; Gravi-
metric Method

53122/2 Testing of Plastic Films, Rubber Films, Paper, Board, and Other Sheet
(1982) Materials; Determination of Water Vapour Transmission; Electrolysis
Method

53356 (1982) Testing of Artificial Leather and Similar Sheet Materials; Tear Growth
Test

53361 (1982) Testing of Artificial Leather and Similar Sheet Materials; Determination
of Suppression at Groove in Coolness

53363 (1969) Testing of Plastic Films; Tear Propagation Test on Trapezoidal Specimens
With a Slit

53377 (1969) Testing of Plastic Films; Determination of Dimensional Stability

53387 (1982) Testing of Plastics and Elastomers; Weathering in Laboratory Apparatus,
Exposure to Filtered Xenon Arc Radiation and Periodic Wetting

53455 (1981) Testing of Plastics; Tensile Test

53495 (1984) Testing of Plastics; Determination of Water Absorption

53504 (1985) Testing of Elastomers; Determination of Tensile Strength at Break,
Tensile Stress at Yield, Elongation at Break and Stress Values in a Tensile
Test

- 53509/1 Testing of Elastomers; Determination of Resistance to Ozone Cracking,
(1980) Static Conditions
- 53509/2 Testing of Rubber and Elastomers; Accelerated Test of Aging in
(1977) Elastomers by Exposure to Ozone; Determination of Ozone Concentration

NBI Standards

- 83 (1983) Building Materials and Components for Exterior Walls, etc. Weather
Resistance, Cyclic Short Time Test
- 92 (1983) Roofing Material. Wind Load Resistance
- 118 (1983) Roofing Material. Penetration by Blows
- 142 (1983) Aging in roof Weatherometer
- 143 (1983) Roofing Material. Ability to Preserve Water Tightness Under Elongation
- 149 (Draft) Building Materials. Movements Under Temperature Changes
- 150 (Draft) Building Materials. Movements Under Changes in Moisture
- NT006 Building Sealants. Deformability Characteristics ("NT" refers to test
methods recognized by all Scandinavian countries--Nordtest Build)

SIA Standards

(Note: these standards have not been translated into English.)

- 183/2 (1976) Verwendung brennbarer Baustoffe in Gebauden, Prufung von Baustoffen
und Bauelementen, Empfehlung (Recommendation for Use of Flammable
Construction Materials in Buildings and Testing of Construction Materials
and Elements)
- 280 (1983) Kunststoff-Dichtungsbahnen, Anforderungswerte und Materialprufung,
Norm (Specifications and Materials Testing for Synthetic Building Paper)

SIS Standards

- 162205 Rubber, Accelerated Aging or Heat Resistance Tests
(1976)
- 162210 Rubber, Determination of Resistance to Ozone Cracking
(1973)

ABBREVIATIONS

ABSAC	Australian Building Systems Appraisal Council, Ltd.
ANSI	American National Standards Institute, Inc.
APP	Atactic polypropylene.
ASTM	American Society for Testing and Materials.
BRI	Building Research Institute (Japan).
CIB	International Council for Building Research, Studies and Documentation.
CGSB	Canadian General Standards Board.
CSTB	Centre Scientifique et Technique du Batiment (France).
DIN	Deutsches Institut fuer Normung (German Standards Institute).
ETI	Hungarian Institute for Building Science.
FM	Factory Mutual Engineering and Research Corporation.
ISO	International Standards Organization.
MOAT	Methods of Assessment and Testing developed by UEAtc.
MRCA	Midwest Roofing Contractors Association.
NBI	Norwegian Building Research Institute.
NBS	National Bureau of Standards.
NRCA	National Roofing Contractors Association
NRCC	National Research Council of Canada.
RILEM	International Union of Testing and Research Laboratories for Materials and Structures.
RMA	Rubber Manufacturers Association.
SBI	Danish Building Research Institute.
SBS	Styrene-butadiene-styrene.
SIA	Swiss Society of Engineers and Architects.
UEAtc	European Union of Agreement.

UFCA Urethane Foam Contractors Association.
 (Now Polyurethane Foam Contractors Division
 of the Society of the Plastics Industry, Inc.)

UL Underwriters Laboratories, Inc.

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